Spin Physics with the PHENIX Detector Upgrade

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- **Introduction**

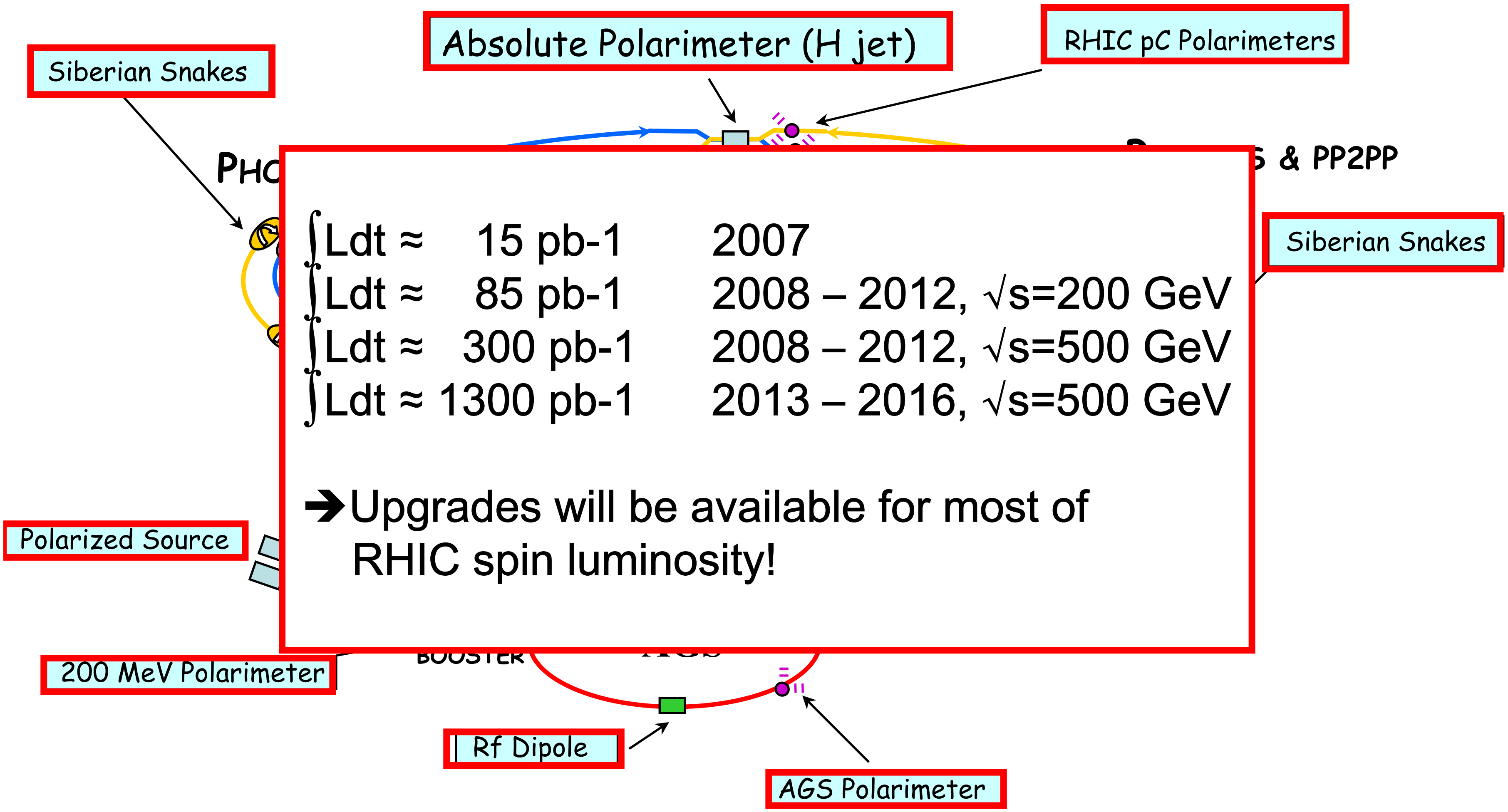
  Nucleon spin structure at RHIC
  Measurements in parallel channels vs DAQ and trigger capabilities
  The importance of low-x
  PHENIX detector Upgrades

- **Physics with the PHENIX detector upgrades**

  ΔG(x) at low x with photons and heavy quarks
  ➔ measurement of ΔG = ∫ ΔG(x)dx.
  Lepton single spin asymmetries in polarized W-production
  ➔ precision measurement + flavor separation of Δq(x), Δq(x)
  Sivers effect in Drell Yan
  ➔ L_z ? , test concepts of factorization + universality in QCD.
  Collins asymmetries
  ➔ measurement of quark transversity distributions.

- **Conclusions**

A novel experimental method: Probing Proton Spin Structure Through High Energy Polarized p-p Collisions



$\int Ldt \approx$ 15 pb-1 2007

$\int Ldt \approx$ 85 pb-1 2008 – 2012, $\sqrt{s}$=200 GeV

$\int Ldt \approx$ 300 pb-1 2008 – 2012, $\sqrt{s}$=500 GeV

$\int Ldt \approx$ 1300 pb-1 2013 – 2016, $\sqrt{s}$=500 GeV

➔ Upgrades will be available for most of RHIC spin luminosity!

Nucleon Structure at RHIC: Physics Highlights

Physics Goals

$\Delta G(x)$	determine first moment of the ***spin dependent gluon distribution***, $\int_0^1 \Delta G(x)dx$.
$G_A(x)$	measure ***nuclear effects*** on the gluon distribution in nucleons in nuclei.
$\Delta q, \Delta \bar{q}$	Flavor separation of ***q and anti-quark spin distributions*** in W-production
δq	measurement of ***trans-versity*** quark distributions.
Sivers Effect	Establish magnitude of the ***gluon Sivers*** effect.

Polarized p-p as a Precision Tool for the Study of Nucleon Structure

(A) Improved theoretical tools: e.g. resummation, NLO perturbative QCD

(B) Build on experimental results from DIS + unpolarized p-p

(C) Consistency: PDFs from DIS + QCD vs cross sections at RHIC

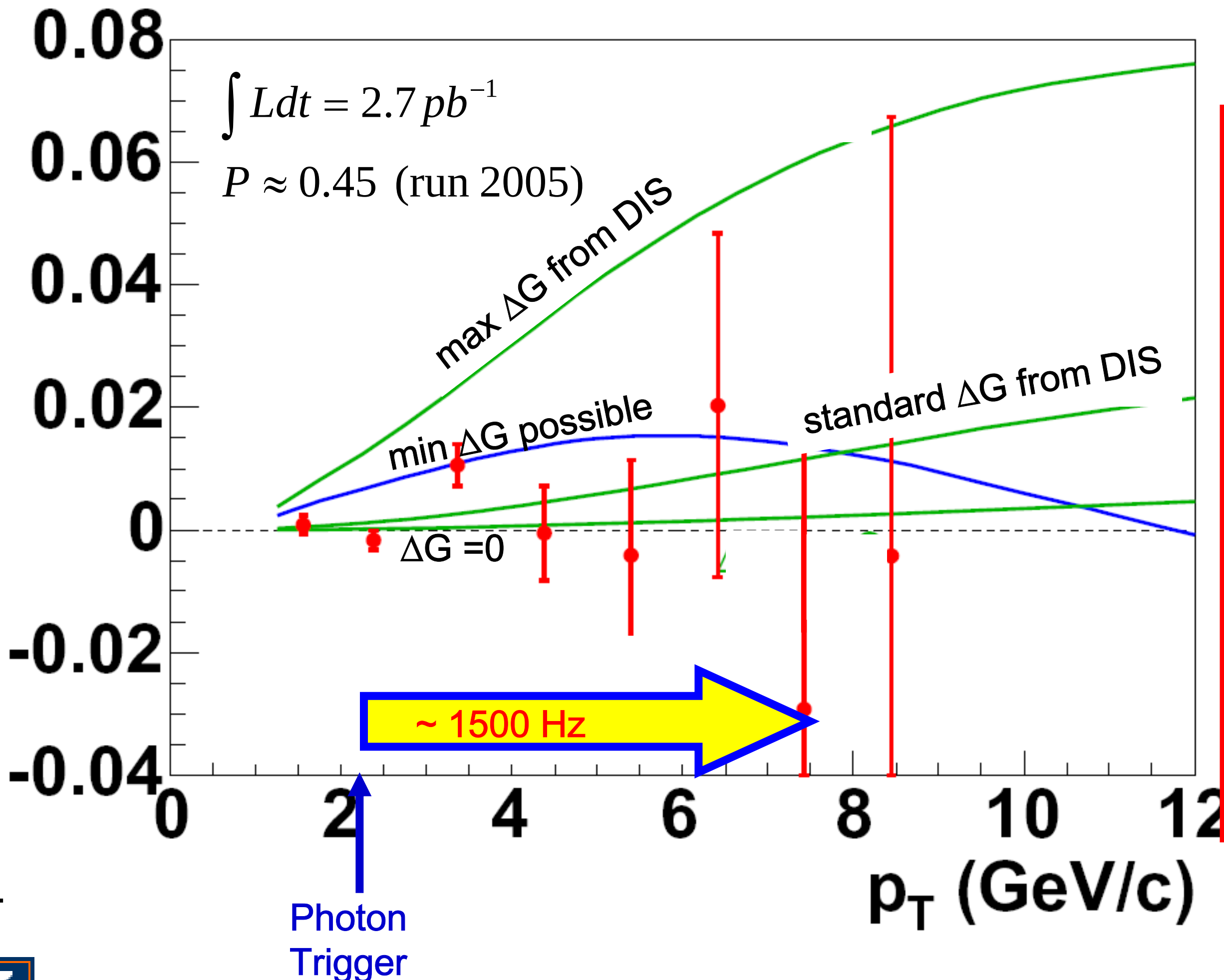
(D) Multiple channels which provide access to spin dependent PDFs with independent experimental and theoretical uncertainties.

e.g. ΔG → inclusive hadrons
→ inclusive photons
→ jet + photon
→ open heavy flavor

Critical: large PHENIX DAQ bandwidth (~ 8kHz) for highest possible rates in multiple channels (including at low p_T!)

Mutiple Channels vs DAQ Bandwidth: Photon Trigger

Run 5 $A_{LL}(\pi^0)$: First constraints for $\Delta G(x)$

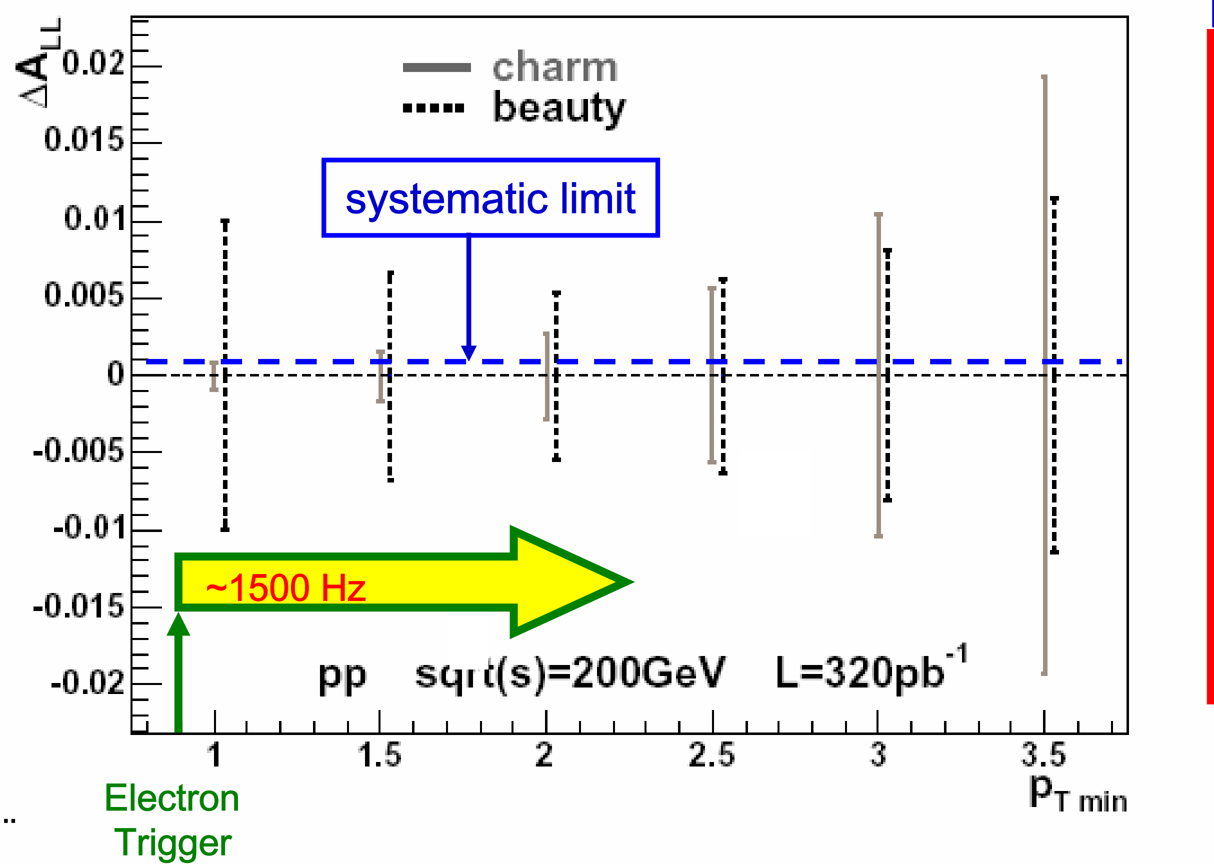


$L=6x10^{31}cm^{-2}s^{-1}$

- → Photon trigger rate for a threshold at 2.1 GeV is ~ 1.5kHz
- → Even at small p_T A_{LL} is statistics limited: $\Delta_{stat}A \sim 2x10^{-3}$, $\Delta_{sys}A < 5x10^{-4}$
- → Continue data taking with low threshold!

Mutiple Channels vs DAQ Bandwidth: Electron Trigger

Future A_{LL}(c,b) Projections with VTX



$L=6x10^{31}cm^{-2}s^{-1}$

→electron rate for a threshold at 0.9 GeV is ~ 1.5kHz

→need $\int Ldt=320pb^{-1}$ before systematics limited at low p_T!

→Continue data taking with low threshold!

Mutiple Channels and DAQ Bandwidth

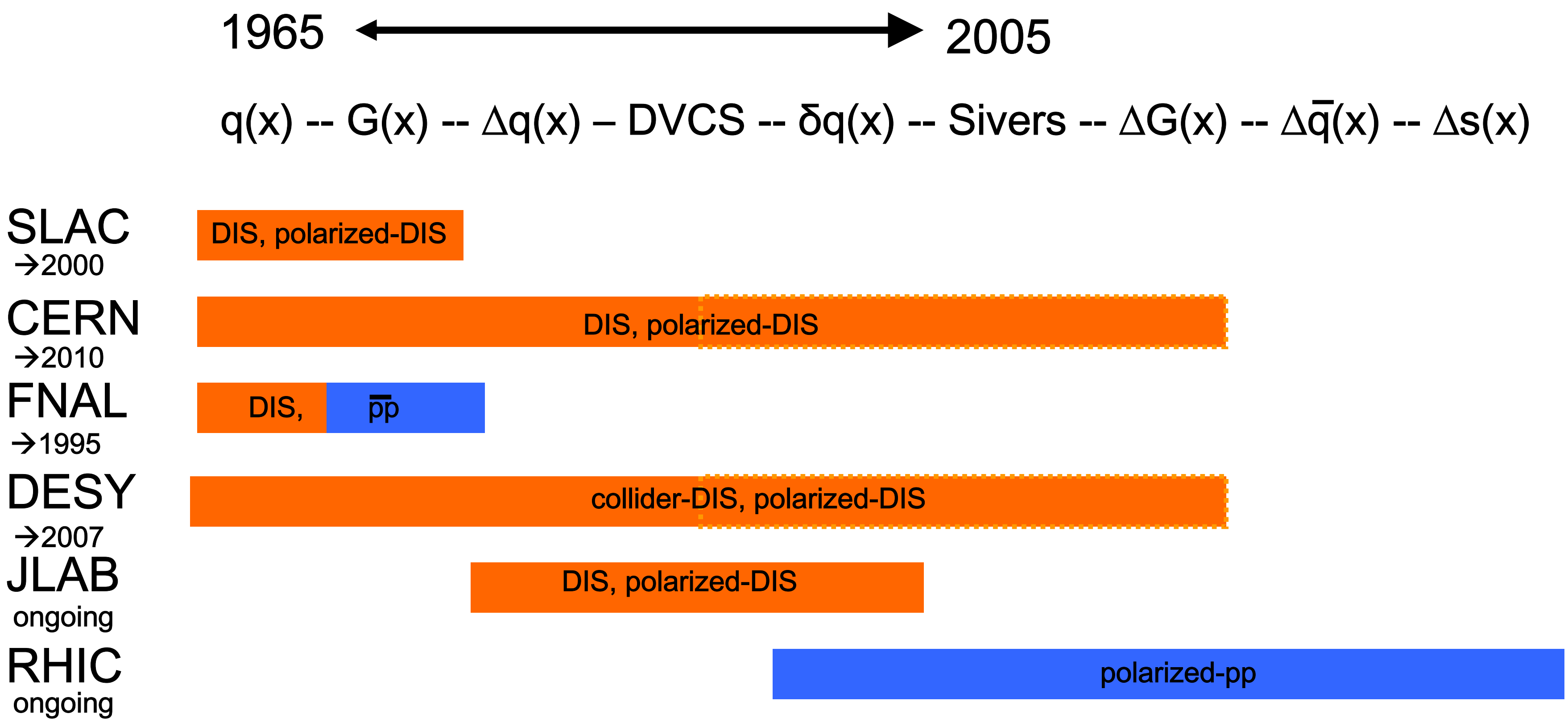
Large bandwidth and trigger capabilities are critical to fully benefit from measurements in multiple channels, e.g. $\Delta G(x)$! PHENIX DAQ and trigger are ideal.

➔ In addition to testing experimental and theoretical uncertainties in independent physics channels this approach leads in PHENIX also to the best statistical precision for results on spin dependent nucleon distribution functions.

Final results on spin dependent observables, e.g. $\int \Delta G(x)\, dx$ will come from inclusive Next-to-Leading-Order perturbative QCD analysis of the asymmetries from all experimental channels.

Low x is important

Nucleon Structure: 40 Years of Experiment
➔ Deep Inelastic Lepton-Nucleon Scattering!



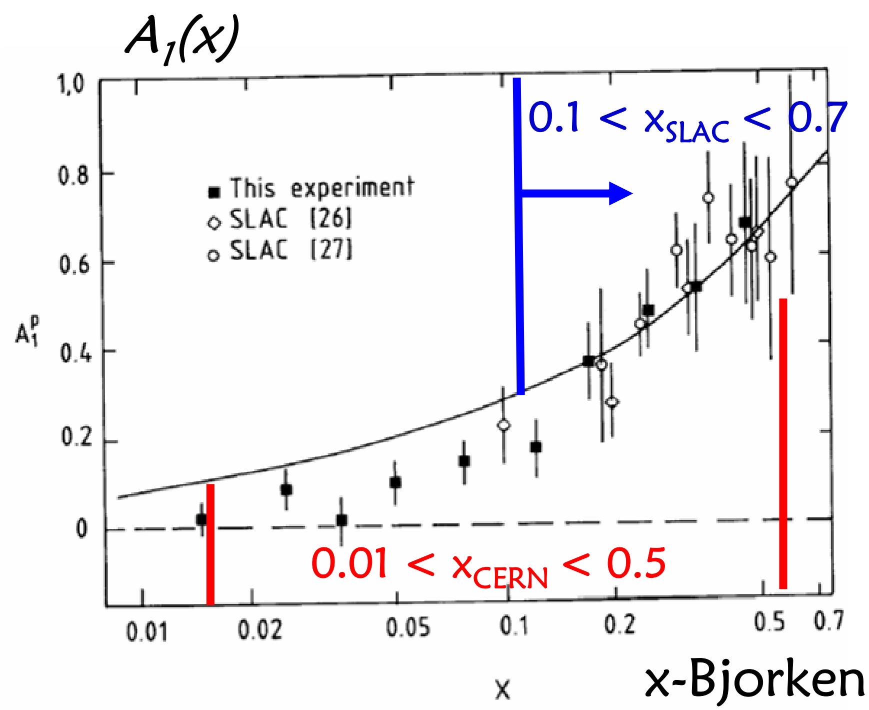
Polarized p-p scattering is a new experimental technique for the precision study of spin dependent nucleon structure and Has to compete in a well established and advanced field.

➔An important "history lesson" is the central role low-x data have played.

The Importance of Low *x* , Example *ΔΣ*

Quark Spin Contribution to the Proton Spin.

Measurements at SLAC: *0.10 < x_{SLAC} <0.7*
vs CERN: *0.01 < x_{CERN} <0.5*



$\Delta\Sigma_{SLAC} \sim 0.6$ QPM expectation !

Evaluation of $\Delta G = \int_0^1 G(x)dx$ requires large x coverage in particular towards low x

$\Delta\Sigma_{CERN}$

EMC, Phys.Lett.B206:364,1988: 1319 citations in SPIRES
EMC, Nucl.Phys.B328:1,1989, 1138 citations in SPIRES

Overview

PHENIX Upgrades

Physics of the PHENIX Detector Upgrades

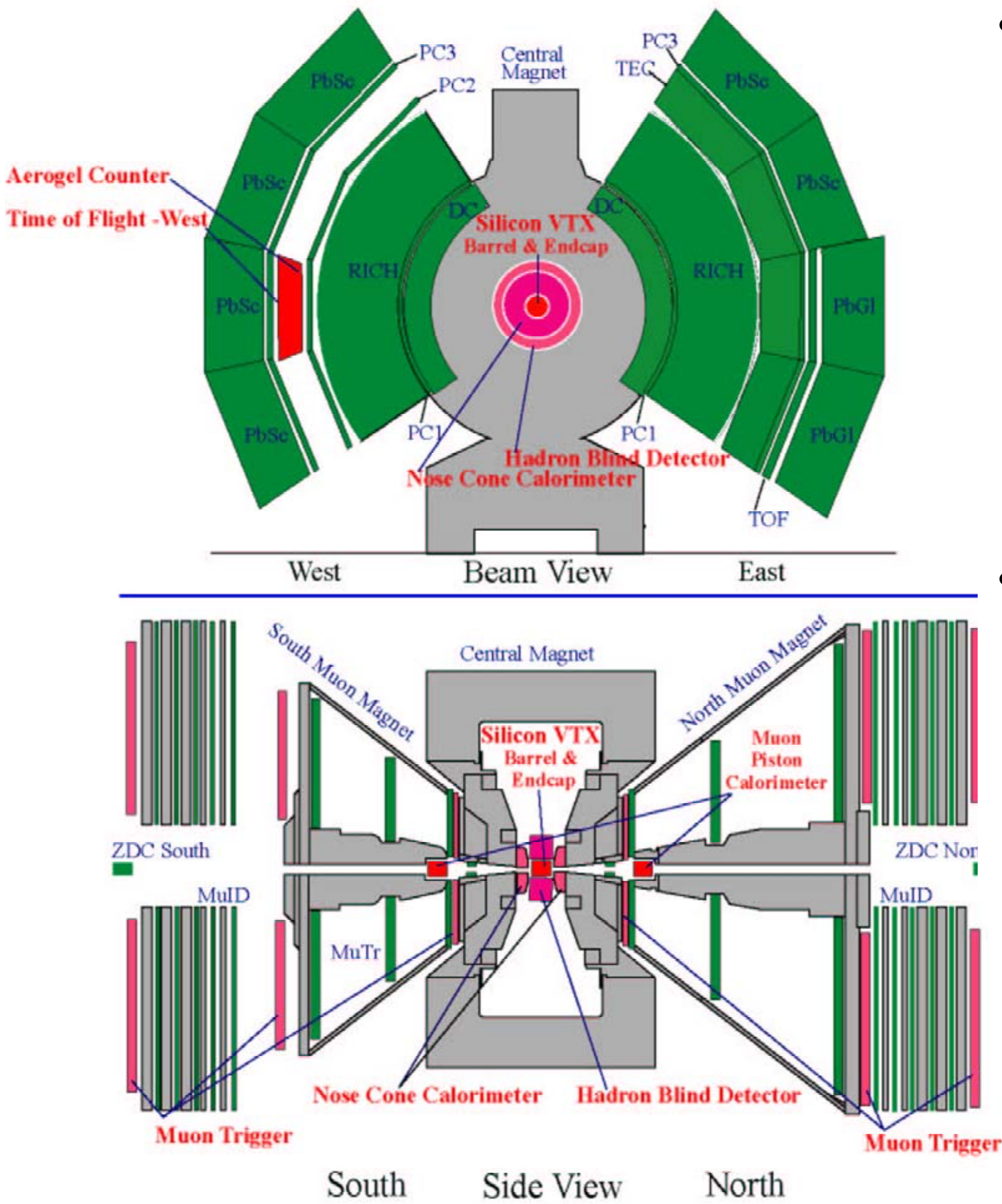
Physics requires highest AA, pA or pp luminosity

- High T QCD (AA, pA, and pp):
  - Electromagnetic radiation (e^+e^- pair continuum)
  - Heavy flavor (c- and b-production)
  - Jet tomography (high p_T PID, jet-jet and γ-jet)
  - Quarkonium (J/ψ, ψ' , χ_c and $\Upsilon(1s),\Upsilon(2s),\Upsilon(3s)$)
- Spin structure of the nucleon:
  - Gluon spin structure $\Delta G/G$ (heavy flavor and γ-jet correlations)
  - Quark spin structure $\Delta q/q$ (W-production)
  - Transverse Spin structure (Collins-jet, Sivers-Drell Yan)
- Low x phenomena
  - Nucleon gluon structure in nuclei → saturation?

Measurements are based on existing detector capabilities + upgrades

PHENIX Detector Upgrades at a Glance

C: complete F: funded P: proposal stage



- Central arms:
  - Electron and Photon measurements
    - o Electromagnetic calorimeter
    - o Precision momentum determination
  - C + Dalitz/conversion rejection – HBD
  - F + Precision vertex tracking – VTX
  - Hadron identification
  - C + PID (k,π,p) to 10 GeV - Aerogel/TOF
- Muon arms:
  - Muon measurements
    - o Identification
    - o Momentum determination
  - F + High rate trigger - μ trigger
  - P + Precision vertex tracking - FVTX
- – Electron and photon measurements
  - P + Muon arm acceptance - NCC
  - C + Very forward - MPC

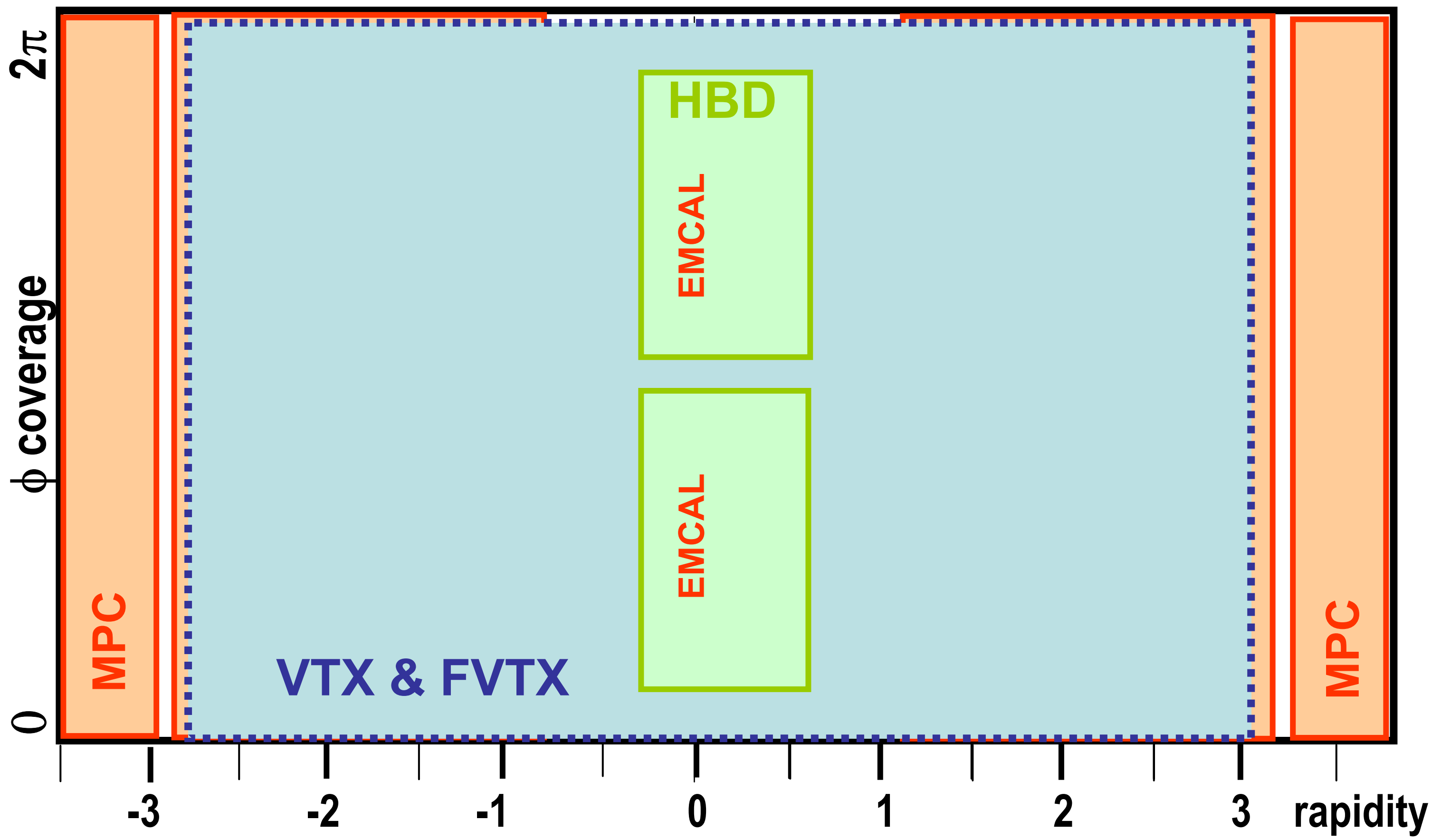
PHENIX Upgrades Physics Capabilities

X upgrade critical for success
O upgrade significantly enhancements program

PHENIX Upgrades	High T QCD				Spin			Low x
	e+e-	heavy flavor	jet tomography	quarkonia	W	DY Sivers	$\Delta G/G$	
hadron blind detector (HBD)	X							
vertex tracker (VTX)	X	X	O	O			X	O
μ trigger				O	X	X		
forward calorimeter (MPC)								X
forward Vertex tracker (FVTX)		X	O	O	O	X	O	O
forward calorimeter (NCC)			O	O	O		O	X
RHIC luminosity	O	O	X	X	O	O	O	O

PHENIX upgrades designed for optimum physics output with RHIC II luminosity spin channels require the highest $\int$Ldt

Upgrades: Future PHENIX Acceptance



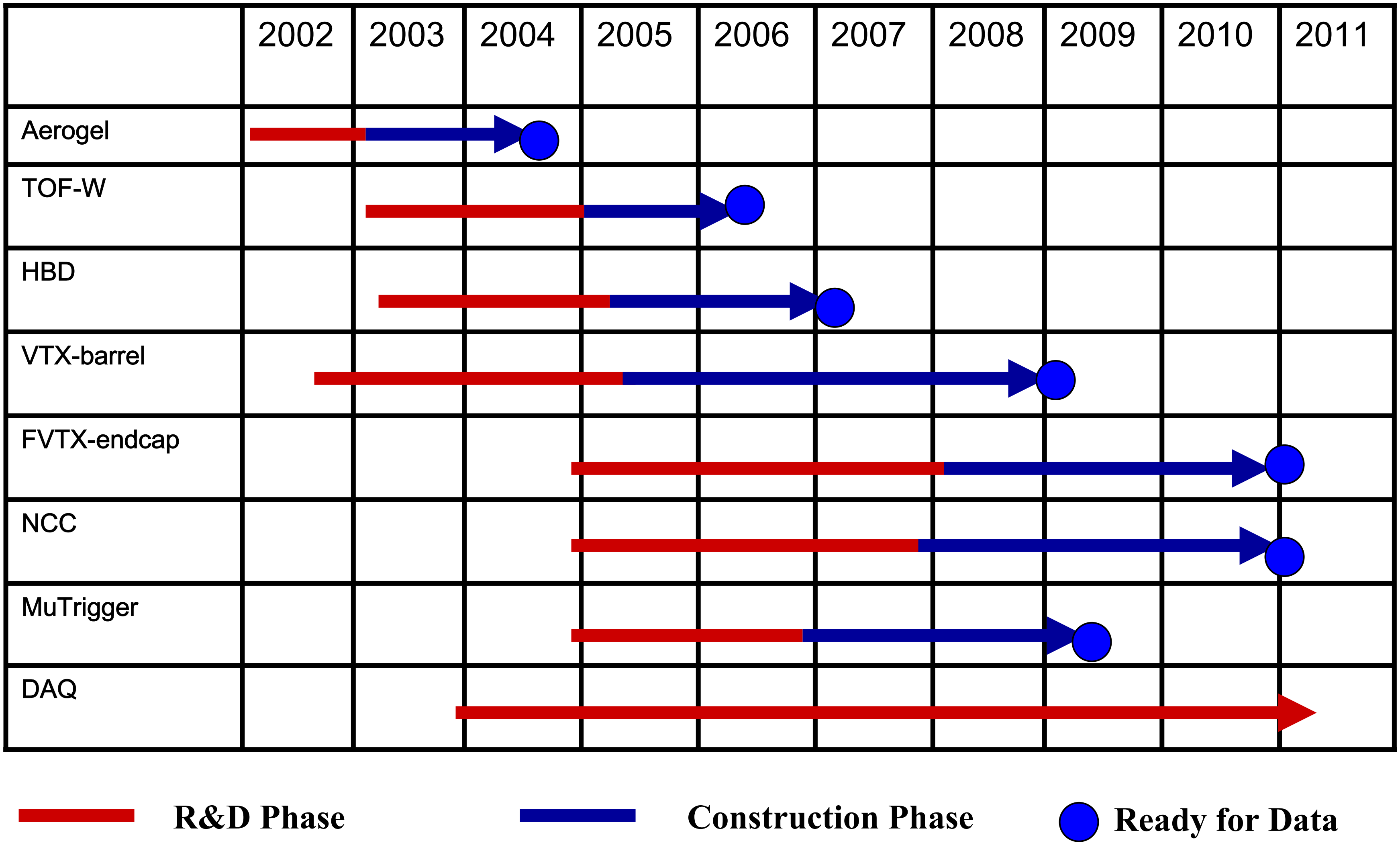
(i) π^0 and direct γ with combination of all electromagnetic calorimeters

(ii) heavy flavor with precision vertex tracking with silicon detectors

➔combine (i) and (ii) for jet tomography with γ-jet

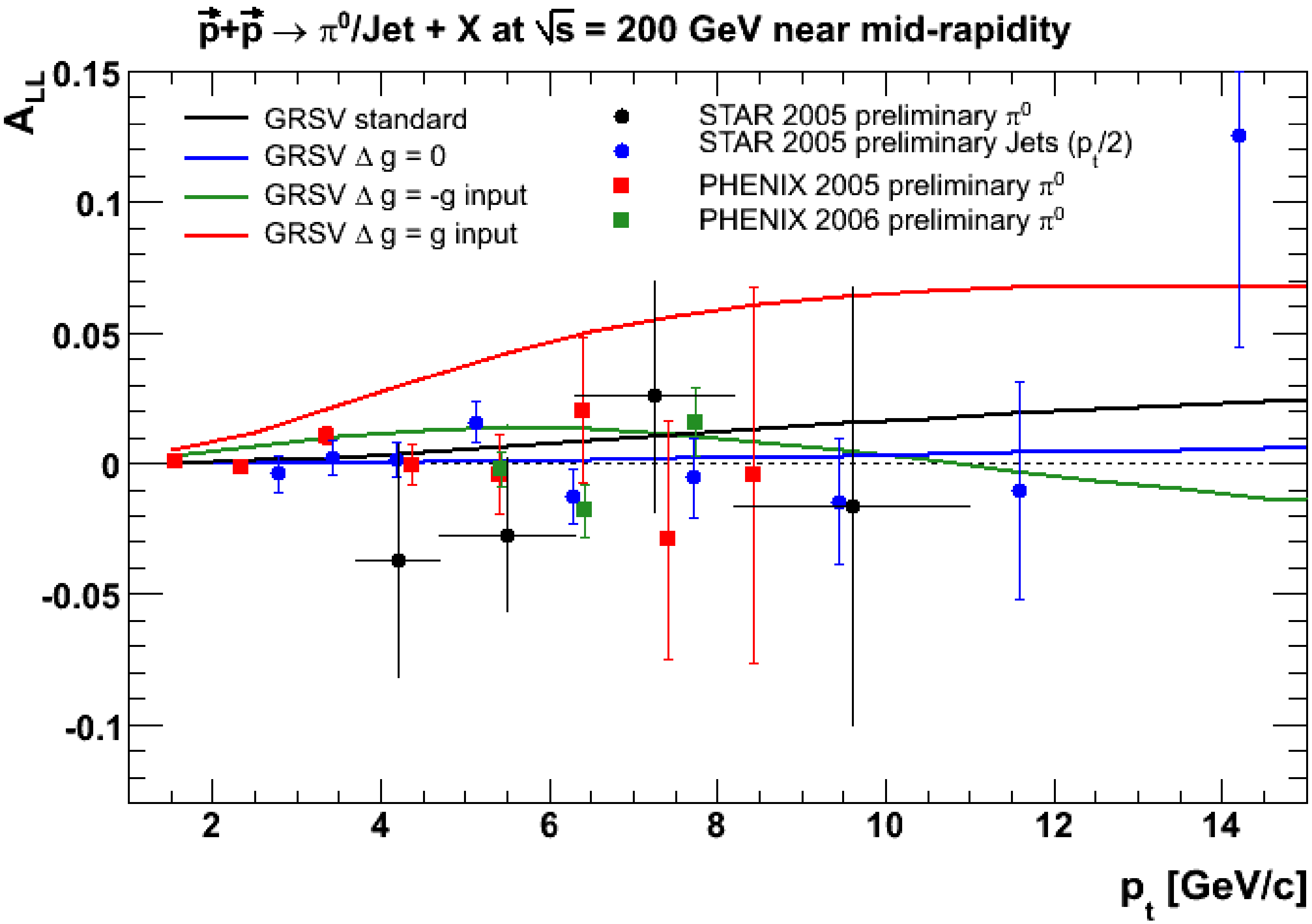
(iii) low mass dilepton measurments with HBD + PHENIX central arms

PHENIX Upgrades Schedule



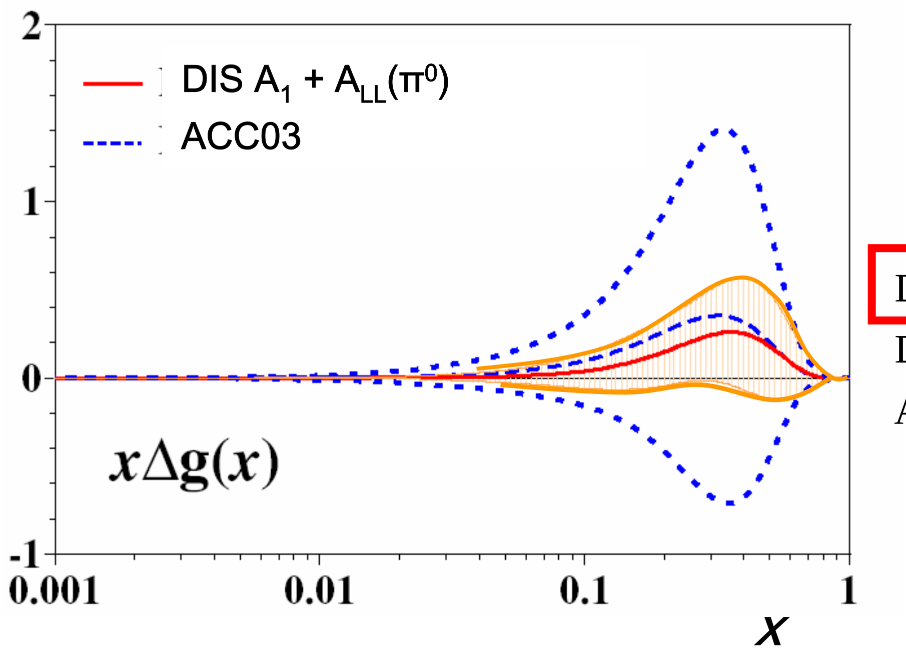
$$\Delta G = \int_0^1 \Delta G(x)dx$$

RHIC: Measurement of $\Delta G = \int_0^1 \Delta G(x)dx$?



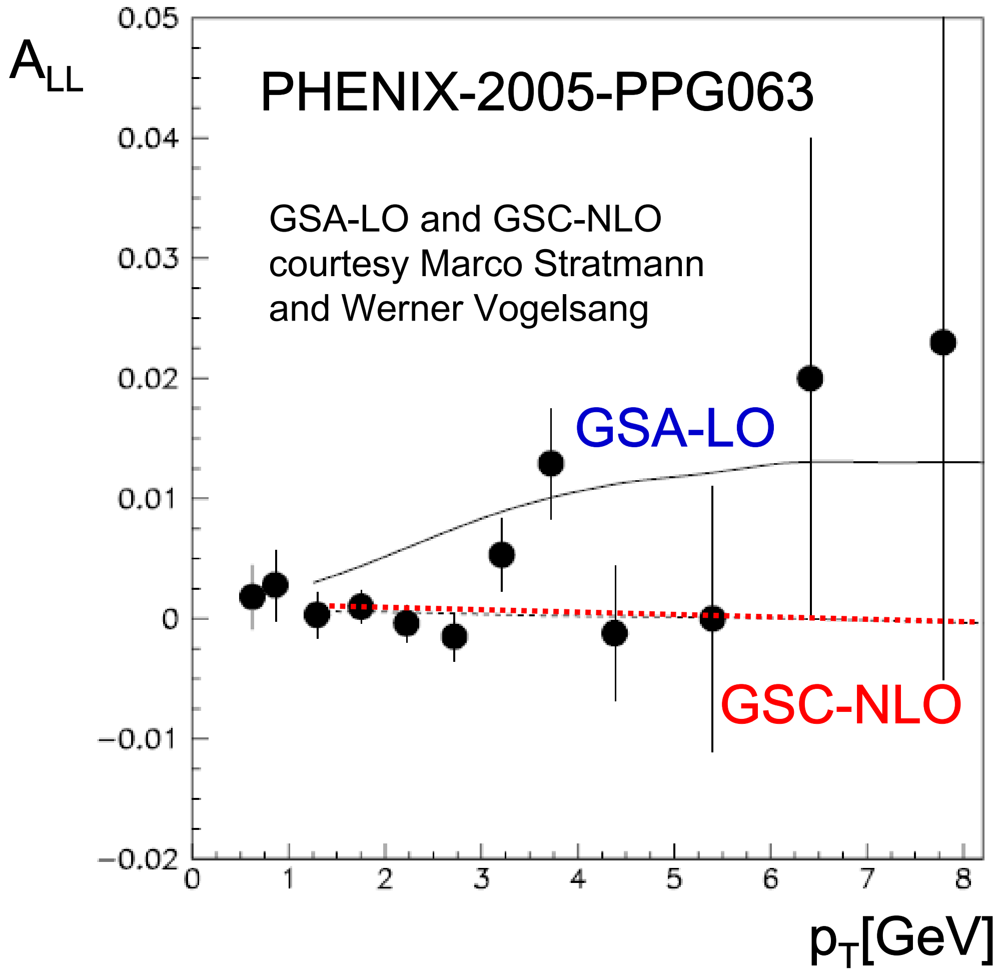
NLO QCD Analysis of DIS A_1 + $A_{LL}(\pi^0)$

M. Hirai, S. Kumano, N. Saito, hep-ph/0603212
(Asymmetry Analysis Collaboration)



	$\int \Delta G(x)dx$	$\Delta\Sigma$
DIS A_1 + $A_{LL}(\pi^0)$	0.31 ± 0.32	0.27 ± 0.07
DIS A_1	0.47 ± 1.08	0.25 ± 0.10
AAC03	0.5 ± 1.27	0.21 ± 0.14

PHENIX π^0 A_{LL} vs GSA-LO and GSC-NLO

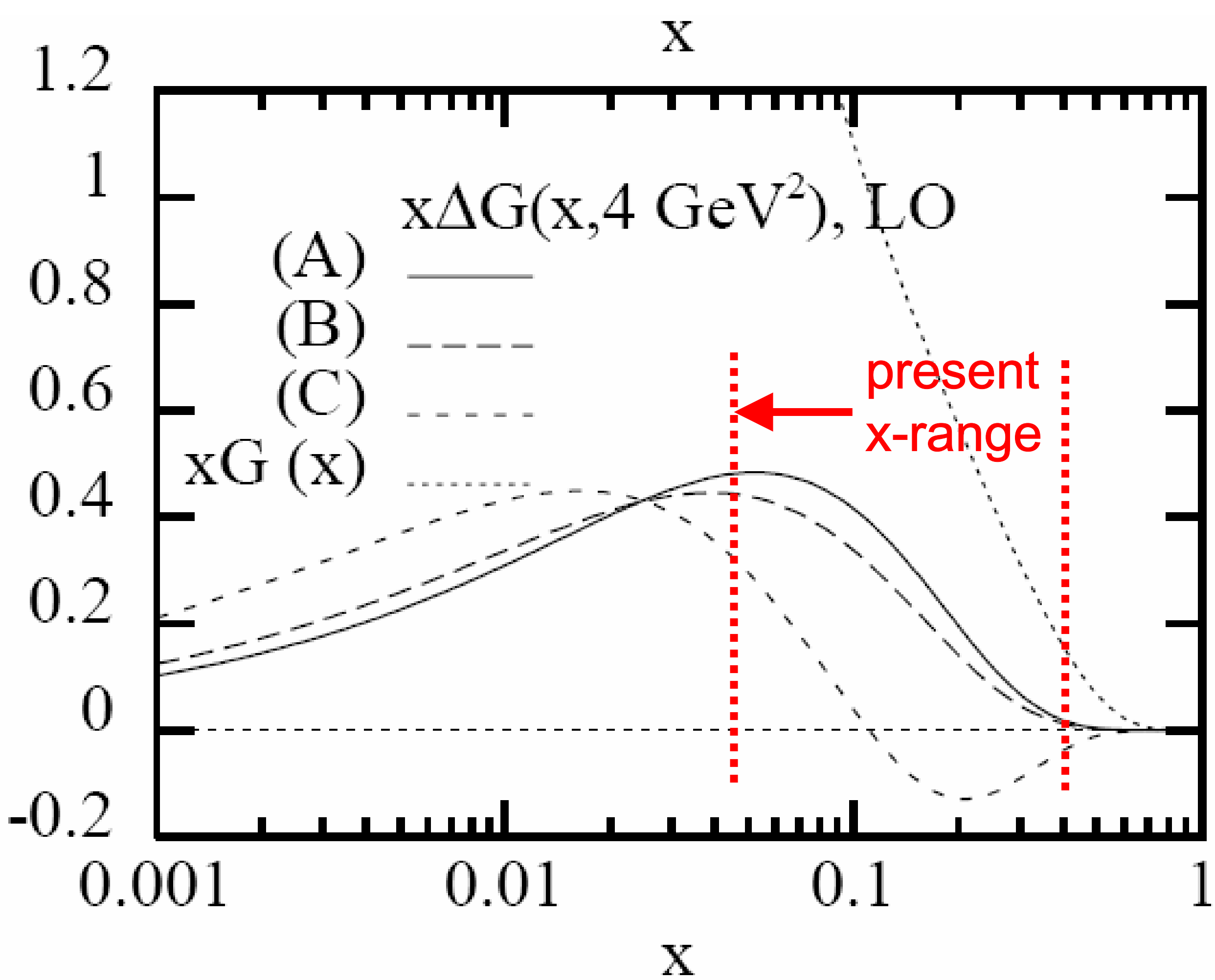


GSA-LO: ***ΔG = ∫ΔG(x)dx = 1.7***

GSC-NLO: ***ΔG = ∫ΔG(x)dx = 1.0***

Large uncertainties resulting from the functional form used for ΔG(x) in the QCD analysis!

ΔG(x) A, B and C from Gehrmann Stirling



Much of the first moment ***ΔG = ∫ΔG(x)dx*** might emerge from low x!

Some theoretical guidance:

ΔG(x) ≤ x G(x)

but *G(X)* diverges faster than x^{-1} *!*

NEED TO EXTEND MEASUREMENTS TO LOW x !!

Next Steps for $\Delta G(x)$ in PHENIX

Increase integrated luminosity by factor 8 (2008)

Extend measurements to low x

➔ Di-hadron Production extends measurements to x → 0.01 (2008)

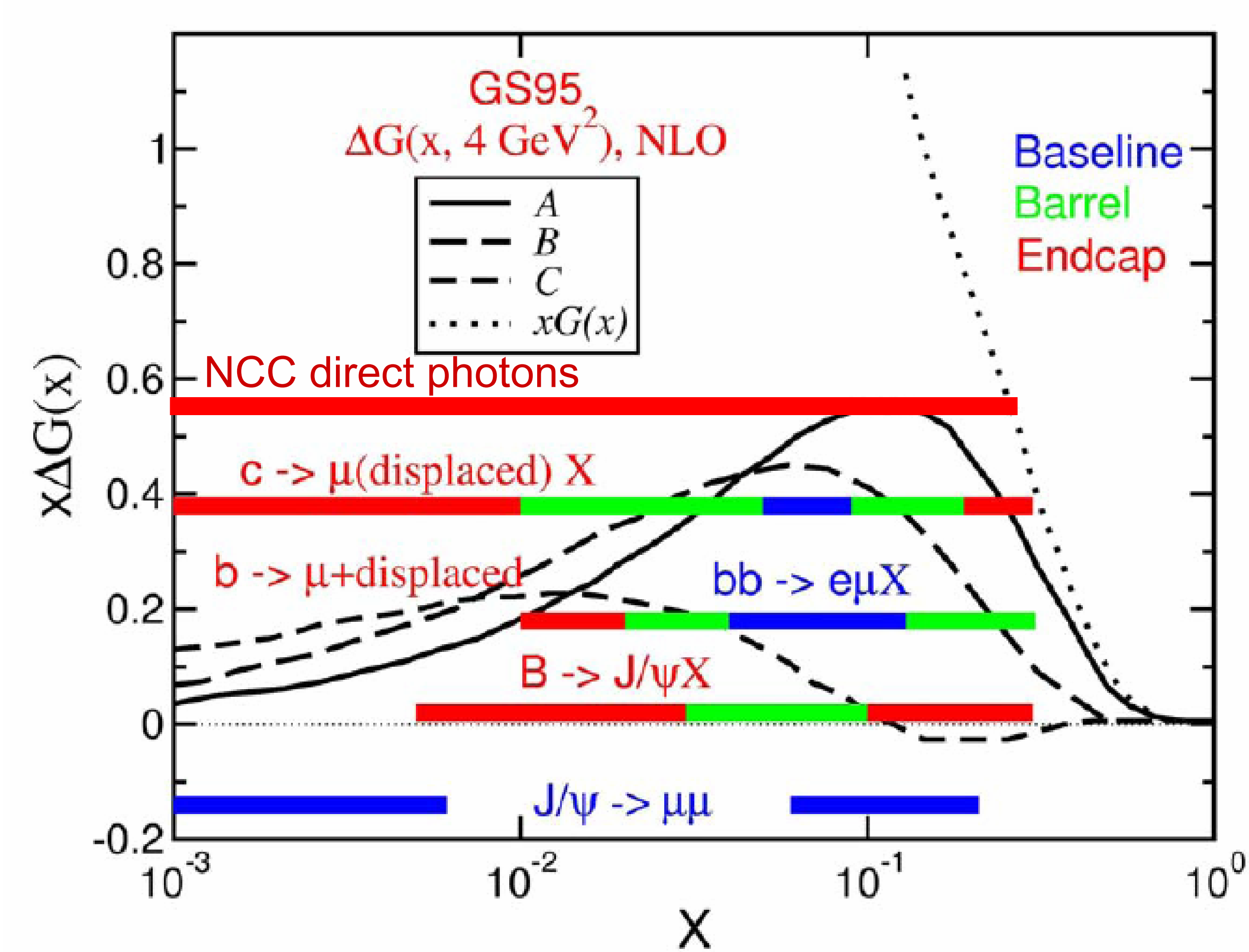
NLO treatment available:
Marco Stratmann -- INPC 2007

(EMC forward calorimeters available
in STAR and PHENIX!)

Forward detector upgrades for direct photons and heavy flavor + highest luminosity (2011→)

reach x → 0.001

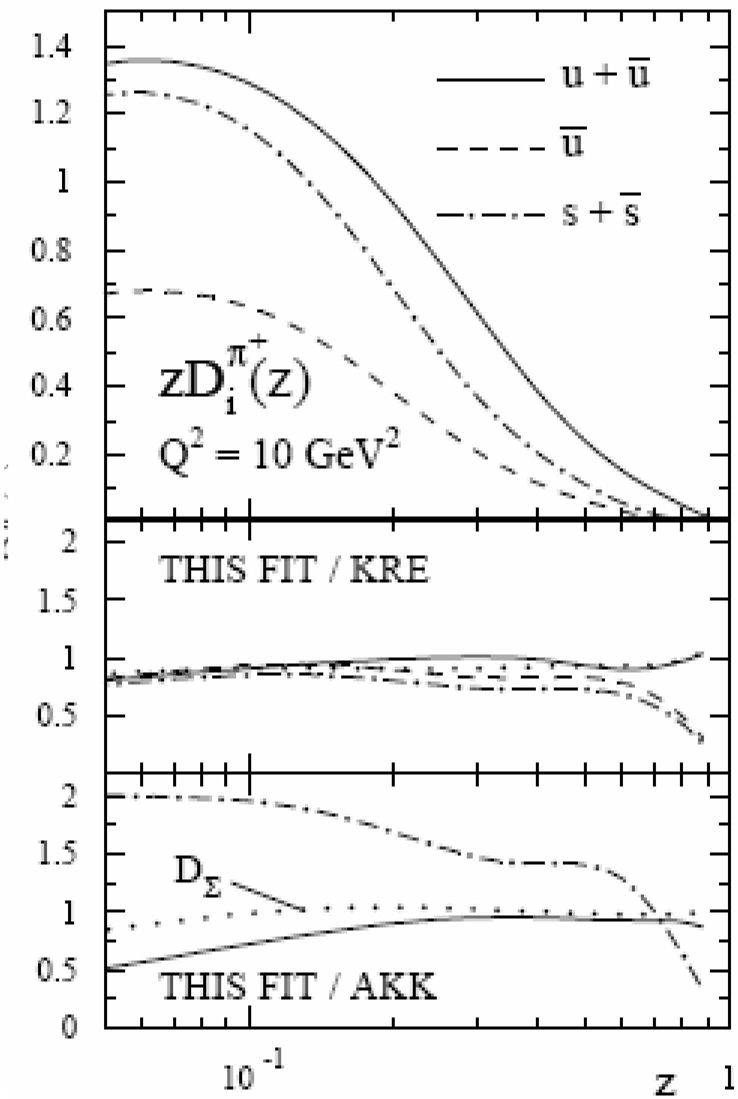
Direct Photons (NCC) + Heavy Flavor (VTX+FVTX)



$$\Delta q(x),\ \Delta \bar{q}(x)$$

Semi-Inclusive DIS: e+p → e+ h +X
Quark & Anti-Quark Helicity Distributions

[HERMES, PRL92(2004), PRD71(2005)]



Future:
Precision DIS at JLAB-12 and at a possible electron – ion collider!

How well do we know hadron fragmentation functions ?

➔ new analysis of e+e- data,
Hirai, Kumano, Nagai, Sudo
hep-ph/0612009, INPC 2007

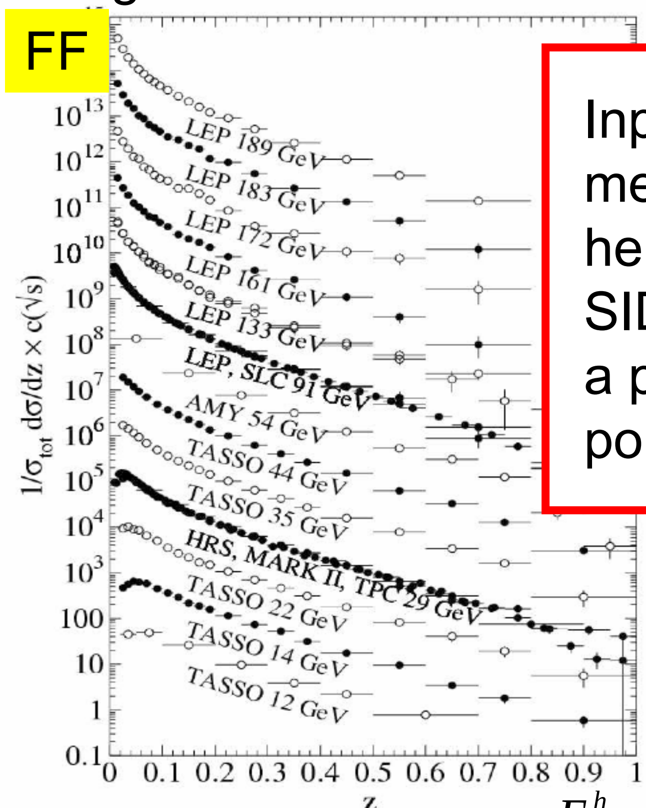
Possible Improvements

➔ include e-p, p-p and e+e- in fragmentation function analysis → done!
De Florian, Sassot, Stratmann
hep-ph/0703242

➔ “add data” from b-factories e+e- → hadrons

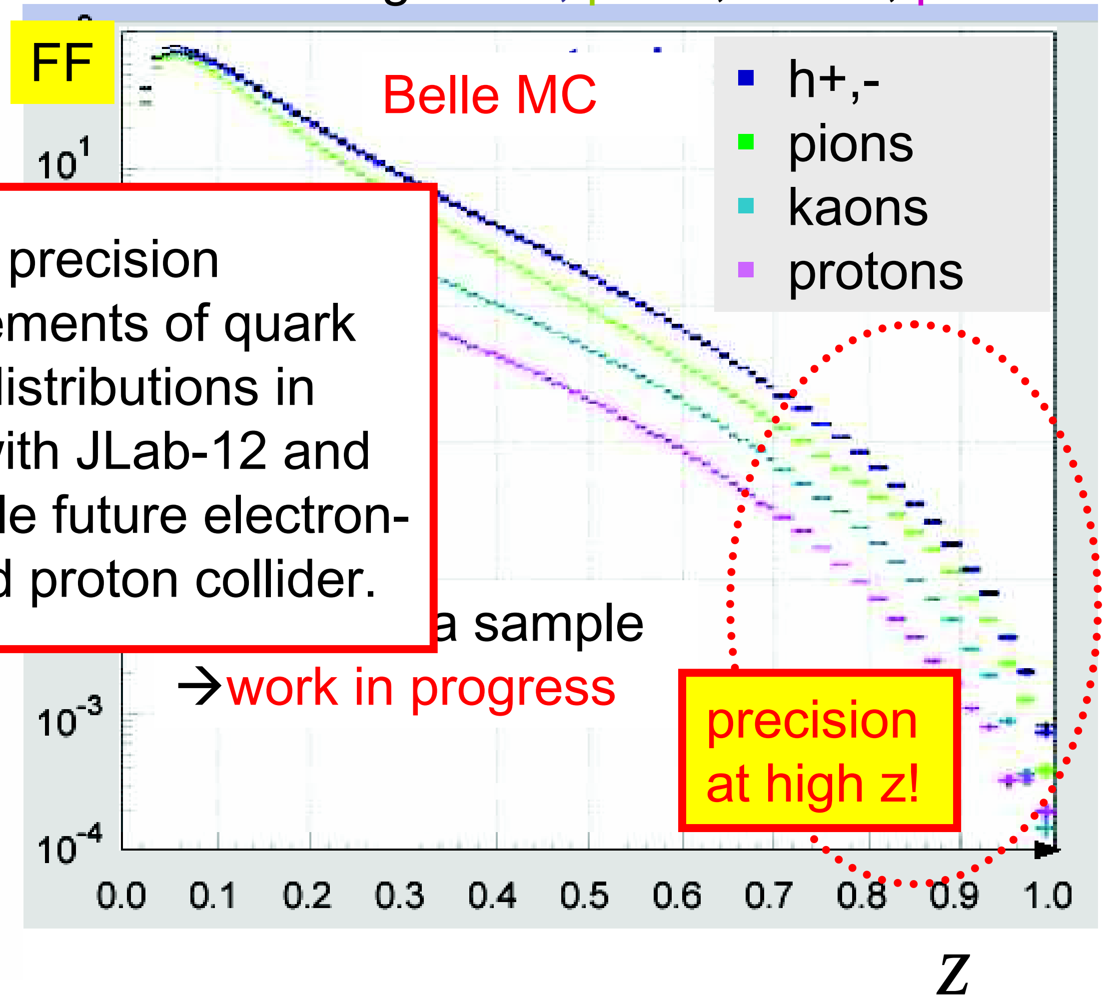
Possible Impact on the Knowledge of Hadron FFs from Analysis of b-Factory Data

Compilation of data available for the charged hadron FF



$$z = \frac{E^h}{\sqrt{s}/2}$$

Belle MC: Charged $h^{+/-}$, pions, kaons, protons



Input for precision measurements of quark helicity distributions in SIDIS, with JLab-12 and a possible future electron-polarized proton collider.

a sample

→work in progress

Another Alternative: W-production at RHIC

SIDIS:

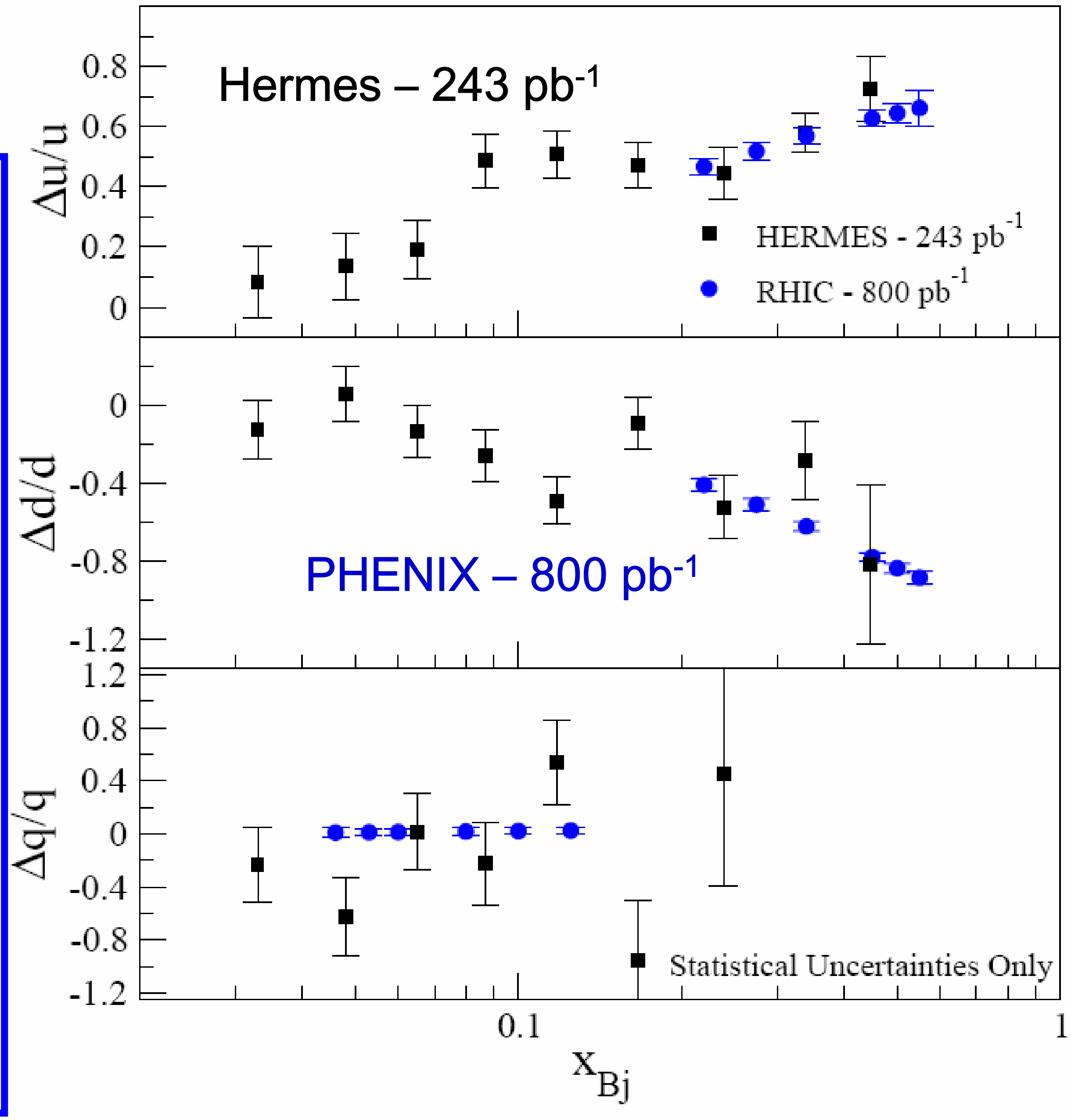
large x-coverage
uncertainties from knowing fragmentation functions

Ws in polarized p-p:

limited x-coverage
high $Q^2 \rightarrow$ theoretically clean
no FF-info needed

Background:

Absorber (S/B 3:1),
isolation using FVTX/NCC
additional factor 3-5



Transverse Spin

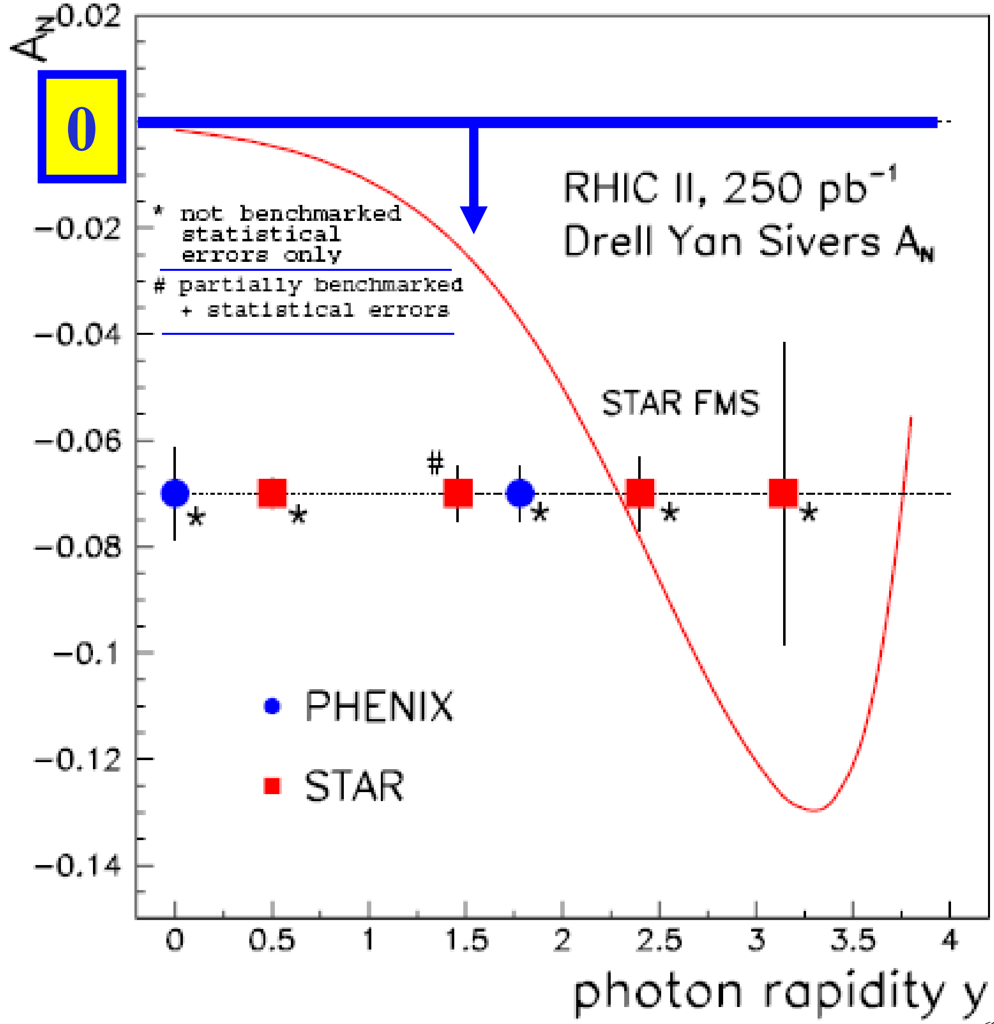
Sivers Asymmetries in Drell Yan

Muon trigger

+

FVTX for heavy flavor background rejection

RHIC II Drell Yan Projections



Nucleon Spin Structure: Physics Impact of VTX, FVTX, NCC and Muon Trigger Upgrades

	Physics Goals	**Present vs with upgrades**
$\Delta G(x)$	determine first moment of the spin dependent gluon distribution, $\int_0^1 \Delta G(x)dx$.	Inclusive hadrons + photons heavy flavor, photons, photon-jet ➔ increase x-range ➔ parton kinematics
$\Delta q(x)$ $\Delta\bar{q}(x)$	flavor seperation of quark and anti-quark spin distri-butions	not possible without upgrades
δq	measurement of trans-versity quark distributions.	A_N for inclusive hadronen A_T in Interference-Fragmentation A_T Collins FF in jets
Sivers Effect	Measurement of the Sivers distributions	A_N for back-to-back hadronen $A_{N,T}$ jets, Ds, DY

Summary

RHIC and it's experiments are the world's first facility capable of colliding high energy polarized protons with high polarization and luminosity.

The planned detector upgrades significantly strengthen PHENIX' capabilities to study nucleon structure:

(1) Measurement of the gluon spin contribution $\int \Delta G(x)dx$

- ➔ **large x-range**
- ➔ **event-by-event kinematics**
- ➔ **heavy flavor + photon jet are new channels with independent experimental and theoretical uncertainties**

(2) First measurements with spin dependent W-production!

(3) Transverse spin: Collins fragmentation and Gluon Sivers in multiple channels. Test fundamental prediciton on non-universality of the Sivers function in Drell Yan!